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The Frame Representation Language (FRL) is described. FRL is an adjunct to LISP which implements several representation techniques suggested by Minsky's concept of a frame: defaults, constraints, inheritance, procedural attachment, and annotation.

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
ARTIFICIAL INTELLIGENCE LABORATORY

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THE FRL MANUAL

R. Bruce Roberts and Ira P. Goldstein

The Frame Representation Language (FRL) is described. FRL is an adjunct to LISP which implements several representation techniques suggested by Minsky's [75] concept of a frame: defaults, constraints, inheritance, procedural attachment, and annotation.

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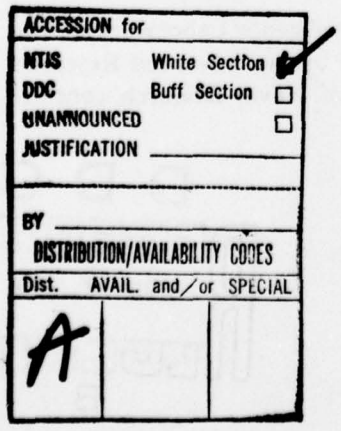
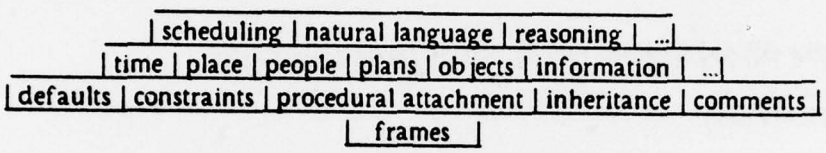


Figure 1 shows FRL from the larger perspective of intelligent support systems. FRL comprises the two bottom layers: a specialized data structure (the frame) and a collection of LISP functions for defining frames, storing and retrieving information. It has been used to implement NUDGE [Goldstein & Roberts 77], a system for maintaining a person's schedule of activities in the face of individual preferences, conflicting constraints, and changing plans; PAL, a natural language front end for NUDGE [Bullwinkle 77]; a system to assist planning a birthday party [Clemenson 77]; TRIPPER, a knowledge base for places and travel around the country [Jeffery 77]; a representation for the discourse structure of news articles [Rosenberg 77]; and COMEX [Stansfield 77], a system for understanding discourse about the commodities market.



- Figure 1 -

The intellectual issues surrounding the representation techniques provided by FRL are discussed in [Goldstein & Roberts 77]. A primer [Roberts & Goldstein 77] is available consisting of an extended example using FRL and an abridged version of this manual.

1. WHAT IS A FRAME IN FRL?

An FRL frame is implemented as nested association lists with at most five levels of embedding. The respective sub-structures of a frame are slot, facet, datum, comment and message. The overall structure of a frame is:

```
(frame1
  (slot1 (facet1 (datum1 (label1 message1 message2 ... more Messages ... )
                         ... more Comments ...)
                 (datum2 (label1 message1 ...))
                   ... more Data ...)
         (facet2 (datum1 (label1 message1 message2 ...)))
           ... more Facets ...)
  (slot2 (facet1 (datum1 (label1 message1 ...) ...)...)...)
    ... more Slots ...)
```

We will refer to the first element in one of these sub-structures as the *indicator* (said to name the structure) and the remaining elements collectively as the *bucket* (in the case of a slot, the bucket is a list of facets, for example). A path of indicators identifies a sub-structure in a frame. The order of sub-structures at any level in a frame is insignificant. In practice, facet names conventionally have a prefix "$"; labels, a suffix ":". This is simply to facilitate their recognition by the programmer.

2. FRAMES AND THEIR NAMES

(FRAME *frame*)

returns a frame structure of the kind shown on the preceding page. An error if *frame* is neither a frame name nor a frame structure.

Unless stated otherwise, a *frame* argument to any function can be either the name of a frame or the frame structure itself.

(FRAME? *frame*)

is like FRAME except returns NIL if *frame* doesn't exist.

(FRAME+ *frame*)

is like FRAME except that if *frame* is a name for a nonexistent frame, a frame is FCREATEd and returned.

(FNAME *frame*)

returns the name of *frame*. An error if *frame* is neither a frame name nor a frame structure.

(FNAME? *frame*)

is like FNAME except returns NIL if *frame* doesn't exist.

(FSLOTS *frame*)

returns a list of the slot names in *frame*.

(FCOPY *frame*)

returns a copy of *frame*.

3. ADDING AND REMOVING FRAMES

(FASSERT *name slot1 slot2 ... slotN*)

creates a frame called *name* (if it doesn't already exist) containing the slots *slot1 ... slotN*. If the *name* frame exists, the new information in the slots is merged with the existing slots. The frame is stored as the FRAME property of *name* and *name* is added to *FRAMES*, the list of known frames. FASSERT is a FEXPR.

The FASSERT switch. If FASSERT is nil, FASSERT forms are not interpreted. This is convenient for selectively reading just the code in a file containing intermixed code and frame definitions.

(FERASE *frame*)

removes *frame* from the FRAME property of its name and its name from the list *FRAME*.

FASSERT and FERASE can cause side-effects if the frame being added or removed contains slots with values. These values are added or removed individually using FPUT and FREMOVE respectively and may trigger the execution of attached procedures. These issues will be considered in greater detail shortly. DEFRAME and FDESTROY, unlike FASSERT and FERASE, have no side-effects.

(DEFRAME *name slot1 slot2 ... slotN*)

creates a frame *name* containing precisely the slots *slot1 ... slotN*. If the *name* frame already exists, its previous definition is FDESTROYed. DEFRAME is a FEXPR.

The DEFRAME switch. If DEFRAME is nil, DEFRAME forms are not interpreted. This is convenient for selectively reading just the code in a file containing intermixed code and frame definitions.

(FDESTROY *frame*)

removes *frame* from the FRAME property of its name and deletes its name from the list *FRAME*.

(FRESET)

removes all frames from the system. It uses FDESTROY.

(FCREATE *{name}*)

creates an empty frame and returns its name. The name will be unique. *Name*, if given, will be used instead, although it may be modified by FGENAME to guarantee uniqueness. Frame names must be atomic.

> Note: Bracketed expressions -- { ... } -- are used in this manual to denote optional arguments. An unbalanced right bracket -- } -- denotes the possible end of the argument list for a LEXPR.

(FGENAME *name*)

returns a guaranteed unique frame name by adding a numerical suffix to *name*.

4. THE AKO AND INSTANCE SLOTS

A slot is a generalization of the attribute-value pair in the traditional LISP property list representation. $VALUE is the slot "facet" which indicates its values. Five

other facets indicate other types of knowledge associated with the slot. Data in the $DEFAULT facet supplies defaults. Data in $IF-ADDED and $IF-REMOVED facets are procedures triggered whenever a slot value is added or removed. $IF-NEEDED data are procedures which may compute a slot value. The $REQUIRE facet holds predicates which describe and restrict the value.

Two slots are recognized by FRL system functions: AKO (A Kind Of) and INSTANCE. These define a relation between frames along which data is inherited. FRL maintains AKO and INSTANCE as inverses. The AKO relation can be used to establish a conceptual hierarchy of frames in which general information stored higher in the hierarchy is inherited by more specialized concepts lower in the hierarchy. Functions like FGET implement this inheritance mechanism.

A relation between frames is defined by making the name of one frame the value of a slot in another frame. The slot names the relation. A tree of frame relations is possible since a slot can have many values. Several functions are provided to examine these relations.

(FCHILDREN *frame slot*)

returns a list of the immediate inferiors of *frame* along the relation named by *slot*. This is just a list of values of *slot*.

(FTREE *frame slot*)

returns a tree of the form (root subtree1 subtree2 ...) with *frame* at the root; each subtree's root is a child of *frame* along the relation named by *slot*.

(FDESCENDANTS *frame slot*)

returns a list of all inferiors of *frame* along the relation *slot* defines. That is, it includes all the frames occurring in the "tree" of FTREE except the root *frame*.

(FRINGE *frame slot*)

returns a list of all "leaves" on the tree of (FTREE *frame slot*).

(FLINK? *slot f1 f2*)

returns T only if a path exists from *f1* to *f2* following only the *slot* "link"; i.e., if one of the values of *slot* of *f1* is *f2*, or FLINK? is true for any of these values.

(AKO? *f1 f2*)

returns T only if *f1* is a kind of *f2*. Equivalent to (FLINK? 'AKO *f1 f2*). Similar definitions are possible for any slot whose value is another frame.

One frame is predefined in FRL: THING. A partial definition of it follows:

```
(THING
  (AKO ($IF-ADDED ( (ADD-INSTANCE) ))
           ($IF-REMOVED ( (REMOVE-INSTANCE) )))
  (INSTANCE ($IF-ADDED ( (ADD-AKO) ))
           ($IF-REMOVED ( (REMOVE-AKO) ))))
```

(FINSTANTIATE *frame {name}*)

creates an instance of *frame* (using FCREATE); i.e., it possesses only an AKO link to *frame*. Its name is derived from *name* (using FGENAME) and will be unique. The newly created frame is returned.

The existence of the AKO link implies a heritage for a frame (or any part of a frame) consisting of all information both in that frame and in all the frames accessible along the AKO link.

(FHERITAGE *frame slot} facet} datum} label}*)

returns a structure formed by merging the structure pointed to by the indicator path -- the arguments to FHERITAGE -- with all corresponding structures of the frames accessible along the AKO link.

The IN Comment. Each datum in the heritage will have a comment -- (IN: *frame*) -- added by FHERITAGE to record the frame in which the datum actually occurs.

(FHERITAGE-SLOTS *frame*)

returns a list of slot names occurring in (FHERITAGE *frame*).

By convention, frames in an AKO hierarchy are distinguished as being either GENERIC or INDIVIDUAL by the value of their CLASSIFICATION slot. Two predicates test the classification of a frame.

(INDIVIDUAL? *frame*)

returns T only if *frame* is marked as an individual. INDIVIDUAL? returns NIL if *frame* is generic, and ? otherwise.

(GENERIC? *frame*)

is defined analoguously to INDIVIDUAL?.

5. ADDING AND REMOVING PARTS OF A FRAME

(FPUT *frame slot} facet} datum} label} message}*)

adds the last argument at the point in *frame* named by the indicator path (the intervening arguments) and returns the modified *frame*. Adding new information to a frame is a merging process that retains the uniqueness of each indicator. FPUT is a LEXPR and can take from 2 to 6 arguments. It can be used to add an element anywhere in a frame; to add a *slot* name to *frame* or to put a *message* in a comment labeled *label*.

FPUT has a side-effect: Putting data items into a $VALUE facet triggers the execution of all procedures in the $IF-ADDED facet of the slot.

(FPUT-STRUCTURE *frame*)
(FPUT-STRUCTURE *frame slot-structure*)
(FPUT-STRUCTURE *frame slot facet-structure*)
(FPUT-STRUCTURE *frame slot facet datum-structure*)
(FPUT-STRUCTURE *frame slot facet datum comment*)

This family of FPUT-STRUCTURE functions differs from FPUT only in that the last argument is considered to be an entire sub-structure (rather than an indicator). The entire structure is merged into *frame*. Like FPUT, FPUT-STRUCTURE may trigger $IF-ADDED procedures.

(FREMOVE *frame slot} facet} datum} label} message}*)

deletes the sub-structure of *frame* indicated by the path *slot - facet - datum ....* It returns the modified *frame*. FREMOVE is a LEXPR taking from 2 to 6 arguments. The structure deleted will have had as its indicator the final argument to FREMOVE.

FREMOVE has a side-effect: If any data in a $VALUE facet is deleted by this command, all procedures in the $IF-REMOVED facet of the slot are executed.

(FREPLACE *frame slot} facet} datum} label} message}*)

like FREMOVEing all existing items following by FPUT with the arguments given. Following a call to this function, the only item present at the terminus of the indicator path is the final argument.

(FDELETE *frame slot} facet} datum} label} message}*)

like FREMOVE except never triggers any side-effects. The portion of *frame* identified by the indicator path is simply excised.

6. RETRIEVING PARTS OF A FRAME

The following questions should be kept in mind when retrieving data from a facet.

- What is the expected form of the data?
- How is the data inherited?
- How does it interact with other facets?
- Are any special comments associated with the data?

But before considering individual facets, three general properties of facets and their data will be discussed: evaluation, indirection, and inheritance.

Evaluation

Normally, data in a frame is interpreted literally. The access functions return just what one sees in a frame if it were printed out. Data can be computed however, and to specify that a datum is to be evaluated whenever accessed, FRL provides:

The % Special Data Form. A percent sign prefixed to a datum causes the evaluated datum to be returned whenever it is accessed.

> The implementation of % as a prefix character requires that it be defined as a readmacro in Lisp. See Appendix A for other changes to the standard MACLISP environment necessitated by FRL's operation.

The data element is evaluated in a particular frame environment, as determined by the frame, slot, and facet named in the retrieval request. The global variables :FRAME, :SLOT, and :FACET at the time of evaluation can be assumed to be locally bound to the names of the "current" frame, slot, and facet. Because of indirection and inheritance, the frame environment may not be the one in which the datum actually lies. Situations may arise when the user will want to explicitly establish a frame environment for the evaluation of an expression. A function has been provided to facilitate this.

(FEVAL *s-expression* [*frame*] [*slot*] [*facet*])

> binds :FRAME, :SLOT, and :FACET to the values supplied. It then evaluates the *S-expression* and returns the result. If an argument is missing or nil, the prior (higher) binding is unaffected.

Indirection

Datum in one frame can be retrieved indirectly by a request for datum in a different frame. This indirection is denoted by:

The @ Special Data Form. A datum with a prefix atsign is interpreted as an indirection pointer to all the data in another frame. The pointer is an indicator path: frame, slot, facet. When accessed, the data items pointed to by the indirection are copied and spliced together with any other items in the facet (generally, a facet can have many data items). The behavior of indirectly accessed items is equivalent to the local items.

A related convention allows one to define a slot in a frame to hold information accessed indirectly by another.

The Non-atomic Slot Convention. If a slot is created whose indicator is non-atomic, the CAR of the slot name is considered to name a *frame* and the CADR a *slot* in *frame*. An indirection pointer is put in each of the existing facets of the indicated *slot* in *frame* pointing back to the corresponding facet of the slot just created.

Comments:

- Each indirect datum returned will receive a comment of the form (IN: *frame*). *Frame* is the name of the target frame lying at the end of the indirection chain.

- Evaluation and indirection are mutually exclusive. A datum may be evaluated, expanded as an indirection pointer, or receive no special processing.

- How does evaluation differ from indirection? Evaluation returns a single datum. Indirection causes a list of data items to be appended to the list of structures returned from the local frame.

- The target of an indirection pointer can be another indirection pointer, in which case the process is repeated. If the target is to be evaluated (i.e., it is a % Special Data From) the evaluation is performed in the frame environment established by the original request.

- The elements of an indirection pointer are evaluated in the frame environment of the indirection pointer.

- Indirection pointers with less than three elements are extended using the :SLOT and :FACET of the current frame.

Inheritance

The AKO relation can be used to establish a hierarchy of frames in which general information stored higher in the hierarchy is inherited by more specialized concepts lower in the hierarchy. These three functions return data inherited along the AKO link of a frame.

(FINHERIT *frame slot facet*)

looks first for data in the *slot* and *facet* of *frame*. If data exists, a list of the datum structures is returned. If no data is found, the corresponding facet of the frame named in *frame*'s AKO slot is inspected for data; and so on until a frame is found containing data -- which is then returned.

Comments:

- Inheritance stops at the first frame along the chain of AKO links whose selected *facet*

contains some data. This precedes any processing of special indicators for indirection and evaluation; hence, an indirect link and a to-be-evaluated datum are seen as non-empty data for the purpose of controlling inheritance. This fact can be used to construct a datum to "mask" the existence of data lying further along the AKO chain. The form -- %NIL -- as the datum element, being non-nil itself, will stop the inheritance of any data from AKO frames; and, assuming it is the only datum element in the facet, will subsequently be evaluated and return NIL.

- If no data is found, FINHERIT returns NIL.

- A frame can be A-Kind-Of more than one other frame; i.e., have more than one value in its AKO slot. FINHERIT traces each of the AKO paths, stopping at the first data encountered along each, and returns a list of all data thus found appended together.

- The FINHERIT Comment. A comment -- (FINHERIT: CONTINUE) -- on any datum structures in a facet causes the inheritance to proceed further along the AKO link as if no data had been found; it returns the local data appended to that found further along the link.

- The IN Comment. A comment -- (IN: *frame*) -- is inserted in each datum returned by the inheritance process, where *frame* is the name of the frame which actually held the datum.

- Subsequent evaluation of inherited data is done in the Frame Environment of the original call to FINHERIT.

The inheritance process defined by FINHERIT is applicable to any facet. The following two variations treat the $VALUE facet specially. In both cases, the inheritance along the $VALUE facet interacts with the $DEFAULT facet.

(FINHERIT1 *frame slot facet*)

Like FINHERIT except if *facet* = $VALUE, before following the AKO path to look for a value, it inspects the $DEFAULT facet of *slot*. This process is repeated at each step up the AKO path. If no values are found, but defaults exist, they are returned instead.

(FINHERIT2 *frame slot facet*)

Like FINHERIT except if *facet* = $VALUE, it is equivalent to:
(OR (FINHERIT *frame slot* '$VALUE) (FINHERIT *frame slot* '$DEFAULT))

Frame Data retrieval

(FGET *frame slot facet*)

returns a list of all the data items in *facet* of *slot* in *frame*. The data is accessed using the function FINHERIT1. Several data items are possible, thus a list is returned. Any

% or @ Special Forms are converted as described in section 4. Each element in the returned list is a complete data item; i.e., its bucket still contains the comments. FGET returns a list of all the indicators in the bucket addressed by the path of arguments. Usually, three arguments are given. The value of a slot is retrieved by (FGET *frame slot* '$VALUE). FGET looks first in the *slot* of *frame*. If data exists, a list of the items is returned. If no data is found, the facet of the frame named in *frame*'s AKO slot is inspected; and so on until a frame is found containing data, which is then returned.

An important special case is FGETting from a $VALUE facet. If still no value is found, FGET repeats, looking in the $DEFAULT facet instead.

The following questions represent useful distinctions to make in retrieving data from a frame database.

- How many items of data are expected?
- Should the data be returned with its Comments?
- Should data marked for evaluation be evaluated?
- Should indirection pointers be chased and the data thus found be included?
- If the frame and slot specified do not yield any data, should any attempt be made to inherit? And if so, what kind? I.e., NONE, FINHERIT, HERITAGE, and, in the case of $VALUE, FINHERIT1 or FINHERIT2.
- Should any $IF-NEEDED procedures be attempted? And if so, what kind? I.e., NONE, IMMEDIATE, REQUEST, DEFAULT, etc.

The FGET function can be parameterized along these dimensions as follows:

(FGET *frame slot facet {keywords}*)

returns data from the indicated facet according to the contents of the *keywords* list. Allowable keywords are:

A / O	All / One	
C / -C	Comments / NoComments	
% / -%	Evaluation / NoEvaluation	(Must be slashified)
@ / -@	Indirection / NoIndirection	(Must be slashified)
0 / 1 / 2 / H / -H	FINHERIT, -1, -2 / Heritage / NoHeritage	

The upper case letters in each keyword are useful abbreviations. As described, FGET without a retrieval key is equivalent to the specification: (A -C % @ 1). Omitted keywords will be supplied from this default specification.

The choice of retrieval keys affects the form of the returned data. ONE and ALL imply a single item or a list of items is returned, respectively. COMMENTS requires that the returned object be in the form of a bucket; whereas the objects returned under NOCOMMENTS are indicators.

Appendix D lists numerous synonyms for common variations of FGET. Retrieving information from a frame database is also accomplished by matching a frame pattern against the frames in the database. The function FFIND will be presented in a forthcoming paper [Rosenberg & Roberts 77] which discusses matching frames in FRL.

Retrieval Functions in a Frame Environment

Frequently one writes a value retrieval expression to be evaluated in a frame environment (i.e., where :FRAME, :SLOT, and :FACET are externally bound); for example, inside an attached procedure. Two special abbreviation forms are recognized in this case to facilitate writing expressions for retrieving the value of a slot using FINHERIT.

The ! Special Form

!(*frame slot*)	= (FGET *frame slot* '(O -C /% /@ 0))
!(*slot*)	= (FGET :FRAME *slot* '(O -C /% /@ 0))
!*slot*	= (FGET :FRAME *slot* '(O -C /% /@ 0))
!!<as above>	= (FGET ... '(A -C /% /@ 0))

The & Special Form

&(*frame slot*)	= (FGET *frame slot* '(O C /% /@ 0))
...	
&&<as above>	= (FGET ... '(A C /% /@ 0))

In both the ! and & special forms, ! forms can be substituted for the *slot* and *frame*. For example, if the MEETING frame has slots WHO and WHERE, an expression -- !(!WHO OFFICE) -- appearing in the $IF-NEEDED procedure of WHERE means the value of the OFFICE slot in the frame for the participant (WHO) of MEETING.

7. THE SEVEN (PLUS OR MINUS TWO) FACETS OF KNOWLEDGE

Several facets have been mentioned so far as participating in the storage and retrieval of information in a frame. This section answers in detail the questions raised in section 6.

The $VALUE facet

Data: The data in a $VALUE facet is an arbitrary S-expression.

Inheritance: FINHERIT, FINHERIT1 or FINHERIT2

Interactions: The $VALUE facet interacts with all other facets.

The $DEFAULT facet

Data: The data in a $DEFAULT facet is an arbitrary s-expression.

Inheritance: FINHERIT.

Interactions: The $VALUE facet (via FINHERITI and FINHERIT2).

The $IF-ADDED and $IF-REMOVED facets

Data in the $IF-ADDED and $IF-REMOVED facets is treated as LISP forms. The forms in the $IF-ADDED facet will be evaluated whenever a value is added to the slot (i.e., in the $VALUE facet) by FASSERT or FPUT. The forms in the $IF-REMOVED facet will be evaluated whenever a value is deleted from a slot (i.e., from the $VALUE facet) by FERASE or FREMOVE.

- No $IF-ADDED procedure will be run if the value was already there. This serves to eliminate loops.

- No $IF-REMOVED procedure will be run if the value was not actually there to be removed.

- The order in which the procedures are run is not fixed.

- The procedures will be run in a frame environment in which the following free variables have been bound:
  :FRAME = *frame*
  :SLOT = *slot*
  :FACET = $IF-ADDED or $IF-REMOVED (as appropriate).
  In addition, the free variable ":VALUE" will be bound to the datum whose addition or removal caused the execution of the attached procedures.

- IF-ADDED and IF-REMOVED procedures are inherited using FINHERIT.

- The APPLY Convention. Interpreting data in the $IF-ADDED and $IF-REMOVED facets as procedures permits the convention that if it is atomic, rather than EVAL'ing it, it is considered the name of a function of no arguments and APPLY'ed to NIL.

(FRUN *s-expression frame} slot} facet}*)

> like FEVAL except for the manner in which it handles atoms. If *S-expression* is atomic, (APPLY atom NIL) is evaluated and the result returned.

The $IF-NEEDED facet

Data: LISP procedures.

Inheritance: FINHERIT.

Interactions: The $VALUE facet.

No explicit functions are predefined to interact with $VALUE because personal conventions are so easily established. For example, a hypothetical:

(FGET-AS-NEEDED *frame slot*)
is equivalent to
(OR (FGET *frame slot*) (FNEED *frame slot*))

where FNEED is predefined:

(FNEED *frame slot {types}*)

runs the $IF-NEEDED procedures associated with *frame* and *slot*; and if one of them returns a value, FNEED returns it. Optionally, only those with a comment of the form (TYPE: *type*) are attempted, where *type* is an element of the *types* list. Suggested useful restricting comments are: request, immediate, and deduce.

Comments:

- The APPLY convention. [See $IF-ADDED]
- Frame Environment. [See $IF-ADDED].
- The $IF-NEEDED Convention. $IF-NEEDED procedures should be written to return nil if they fail to add a value to the slot.

The $REQUIRE facet

Data items in the $REQUIRE facet should be a LISP predicates which describe allowable values for the slot. There is an implicit conjunction between all data items present. Consistent with the view of specialization as involving additional restrictions on more general concepts, $REQUIRE data is inherited by taking the Heritage. The predicates are evaluated in the appropriate frame environment, as with the other procedural knowledge already discussed.

Checking requirements In FRL, requirement checking is done using the following function to maintain the so-called :VALUE convention.

(FAPPLY-CONSTRAINTS *constraints values*)

returns a poll (see FPOLL) produced by evaluating each of the constraints. A constraint is any S-expression with a Boolean value. FAPPLY-CONSTRAINTS binds

the free variables :VALUE and :VALUES, by which constraints can refer to potential values. If *values* has only one element, it is bound to :VALUE and *values* to :VALUES; otherwise, :VALUE = NIL.

(FPOLL *predicates*)

evaluates the predicates and records whether each was T, NIL, or caused an error. Returns a poll:

```
(<summary> (T ... true predicates ...)
           (NIL ... false predicates ...)
           (? ... error-producing predicates ...))
```

where the <summary> is T only if all are true, NIL only if some are false and none produce errors, and ? otherwise.

(FPOLL-SUMMARY *predicates*)

like FPOLL but returns only the "summary" portion, not the entire poll.

(FCHECK *frame slot {values}*)

returns a poll of all constraints in the $REQUIRE facet of *slot* in *frame* applied to the values of the slot. Both local and inherited constraints are included. If optional *values* are supplied, they are checked against the constraints instead. Constraints are run in a Frame Environment with :FRAME, :SLOT and :FACET bound. Moreover, :VALUE and :VALUES are bound as described in FAPPLY-CONSTRAINTS.

Utility functions for predicates The treatment of predicates has been extended to include an explicit value for unknown, ?, as well as T or NIL.

(TRUE? *x*)

returns T only if *x* is neither NIL nor ?.

(FALSE? *x*)

returns T only if *x* is NIL.

(UNKNOWN? *x*)

returns T only if *x* is ?. The value of ? is ?.

8. ANNOTATING DATA IN FRAMES

Any data item can have several comments. Three labels are recognized by FRL:

IN:

The accompanying message is the name of the frame in which the data is stored. This comment is added automatically by FRL when the data is first accessed and by FHERITAGE.

FINHERIT:

The only recognizable message is CONTINUE. This tells FINHERIT to return data found further along the AKO chain appended the to data in the current frame.

TYPE:

Recognized by FNEED as the label for a message which is a type of $IF-NEEDED procedure. FNEED may selectively evaluate these procedures.

Comment Functions. These functions manipulate the comments of a datum object.

(FADD-COMMENT *datum comment*)

merges the comment specified by *label* and *message* into the *datum*. FADD-COMMENT returns the modified *datum*.

(FCOMMENT? *datum label {message}*)

tests whether the *datum* has a comment matching the *label* and (optional) *message*. If so, it returns the comment. The comment matches if it includes *message* among its messages.

9. SAVING FRAMES IN A FILE

Saving the state of a frame in FRL is accomplished with either of the next two functions.

(FDUMP *frames file*)

outputs in *file* each frame in the list *frames* in DEFRAME form, ready to be read back in using the ordinary LISP reader.

(FSAVE *frames file*)

outputs in *file* each frame in the list *frames* in FASSERT form, ready to be read back in using the ordinary LISP reader.

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Appendix A -- The FRL LISP Environment

A.1 Interrupt Character Definitions.

^E

Edit a function using LEDIT. It must previously have been read using CLOAD or FLOAD. See LEDIT documentation for further information. Actually, the value of *EDITOR* is the editor used by ^E.
^E*function* edits the function.
^E(*<file names>*) edits the file.
^E() re-edits the previous object.

^F

^F*frame* prints *frame*.
^F(*frame slot*) prints the *slot* of *frame*.
^F(*frame slot facet* ...) prints the structure accessed by the path *frame, slot,* ....
^F() reuses the previous argument.

^P

^P*function* prints *function*.
^P(*atom indicator*) prints the *indicator* property of *atom*.
^P() reuses the previous argument.

---

^^ Print a backtrace.

^\ Examine the stack; using (DEBUG).

^● Step through the next evaluation; (STEP t).

A.2 Control Characters in FRL.

(* => non-standard LISP definition)

@*	(STEP t)
A*	record the TV screen in a file
B	enter breakloop
C	GC statistics OFF
D	GC statistics ON
E*	edit a function
F*	print a frame
G	quit to toplevel
H	<backspace>
I	<tab>
J	<linefeed>
K	redisplay input buffer; deletes a line during type-in to "_" prompter
L	erase screen and redisplay input buffer
M	<newline>, behaves like space
N*	delete word during type-in to "_" prompter
O	*unused*
P*	print a function
Q	enable file input
R	enable file output
S	disable terminal output until next READ
T	*unused*
U*	undoes type-in during ">" prompted request, then reprompts.
V	enable terminal output
W	disable terminal output
X	quit to errset
Y	*unused*
Z	quit to DDT
[*	<altmode>
*	(DEBUG)
]	*unused*
^*	Print backtrace
_	*unused*

A.3 Syntax Table Definitions.

The characters @, %, !, and & are readmacros which read the next S-expression and respectively expand into (ATSIGN *s-expression*), (PERCENTSIGN *s-expression*), (EXCLAMATION *s-expression*), and (AMPERSAND *s-expression*).

(FRL-READTABLE) selects this readtable. (LISP-READTABLE) selects the standard LISP readtable.

A.4 Global System Variables.

The following global variables are used by FRL:
FASSERT, DEFRAME, *FRAMES*, *NEW-FRAMES*, :USER, :FRAME, :SLOT, :FACET, :VALUE, :VALUES, PAGEPAUSE, *VERSION*, *FGENSYM*, *REQUEST-PROMPTER*, *DEBUG*, *VERBOSE*.

A.5 How big is FRL?

Binary Program Space	26000 words
Lists	16324
Fixnum	5323
Symbol	1662

Appendix B -- Frames are built out of FLISTS

The foundation of FRL consists of a few LISP functions for manipulating flists. An flist is a recursive list structure defined as follows:

flist ::= (*indicator* . *bucket*)
indicator ::= *s-expression*
bucket ::= (*item item* ...) [A bucket can be NIL]
item ::= *flist*

In FRL, flists are implemented as nested association lists. An embedded flist can be identified by specifying a path of indicators.

D.1 An Flist has two parts -- an INDICATOR and a BUCKET.

(FINDICATOR *flist*)

returns the indicator from *flist*.

(FBUCKET *flist*)

returns the bucket from *flist*.

(FINDICATORS *flist*)

returns a list of the indicators of the items in the bucket of *flist*.

(FINDICATORSl *bucket*)

returns a list of the indicators of the items in *bucket*.

D.2 Retrieving items from an Flist.

(FLISTGET *flist ind1 ind2 ... indN*)

returns the flist whose indicator matches *indN*; reached by first selecting the item in the bucket of *flist* whose indicator matches *ind1* and then reapplying FLISTGET to this item (which is an flist itself) with remaining arguments *ind2 ... indN*. Thus, the indicators define a path leading deeper into the flists nested as items in *flist*. The analogy with LISP's GET function is not coincidental. NIL is returned if the path leads nowhere; i.e., either the embedding is less than *N* or no items at that level match *indN*.

D.3 Storing items in an Flist.

(FLISTPUT *flist item ind1 ind2 ... indN*)

adds *item* to the bucket pointed to (as in FLISTGET) by the indicator path *ind ... indN*. FLISTPUT then returns the modified *flist*. If the path formed by *ind1 ... indN* does not exist in *flist*, one is constructed. The order of FLISTPUT's arguments reflects its similarity to LISP's PUTPROP function, but with extra indicators specifying a complete path. If an item EQUAL to *item* already exists in the bucket, FLISTPUT does nothing; i.e., addition to an flist is a merging operation. Items in a bucket are always assumed to be unordered.

D.4 Deleting items from an Flist.

(FLISTDELETE *flist ind1 ind2 ... indN*)

deletes the entire item accessed in *flist* via the indicator path *ind1 ... indN*; i.e., it will have had *indN* as its indicator. FLISTDELETE returns the modified *flist*.

(FLISTCLEAR *flist ind1 ind2 ... indN*)

empties the bucket under *indN*, but leaves the indicator. FLISTCLEAR returns the modified *flist*.

(FLISTREPLACE *flist item ind1 ind2 ... indN*)

Item displaces all existing items in the bucket accessed in *flist* via the indicator path *ind1 ... indN*. It is equivalent to an FLISTCLEAR followed by an FPUTLIST. FLISTREPLACE returns the modified *flist*.

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Appendix D -- Table of Data Retrieval Functions

Some instances of data retrieval are common enough to justify a unique name. A popular collection follows in tabular form, grouped according to the type of inheritance used to retrieve the data. The general form for the following functions is:

(<function> *frame slot facet*).

Retrieval function	count	comment	evaluate	indirect	inherit	(*returns*)
*fdatum-only	ONE	NO	YES	YES	NONE	indicator
*fdata-only	ALL	NO	YES	YES	NONE	list of indicators
*fdatum	ONE	YES	YES	YES	NONE	bucket
*fdata	ALL	YES	YES	YES	NONE	list of buckets
fdatum-only	ONE	NO	YES	YES	0	indicator
fdata-only	ALL	NO	YES	YES	0	list of indicators
fdatum	ONE	YES	YES	YES	0	bucket
fdata	ALL	YES	YES	YES	0	list of buckets
fheritage	ALL	YES	YES	YES	HERITAGE	list of buckets

The general form of the following functions is:

(<function> *frame slot*).

*fvalue-only	ONE	NO	YES	YES	none	indicator
*fvalues-only	ALL	NO	YES	YES	none	list of indicators
*fvalue	ONE	YES	YES	YES	none	bucket
*fvalues	ALL	YES	YES	YES	none	list of buckets
fvalue-only	ONE	NO	YES	YES	0	indicator
fvalues-only	ALL	NO	YES	YES	0	list of indicators
fvalue	ONE	YES	YES	YES	0	bucket
fvalues	ALL	YES	YES	YES	0	list of buckets
fvalue-only1	ONE	NO	YES	YES	1	indicator
fvalues-only1	ALL	NO	YES	YES	1	list of indicators
fvalue1	ONE	YES	YES	YES	1	bucket
fvalues1	ALL	YES	YES	YES	1	list of buckets
fvalue-only2	ONE	NO	YES	YES	2	indicator
fvalues-only2	ALL	NO	YES	YES	2	list of indicators
fvalue2	ONE	YES	YES	YES	2	bucket
fvalues2	ALL	YES	YES	YES	2	list of buckets

Some general naming rules have been observed. "-ONLY" signifies that the comments have been stripped off. "*" denotes no inheritance. Singular and plural forms distinguish functions which return a list of all data items from those that expect to find a

single datum.

The following predicates return T only if data exists to be retrieved; i.e., if the corresponding retrieval function (see Table) would return non-nil. The predicate forms, however, do not return useable data.

(*FDATUM? *frame slot facet*)
(FDATUM? *frame slot facet*)
(FHERITAGE? *frame slot facet*)
(*FVALUE? *frame slot*)
(FVALUE? *frame slot*)
(FVALUE1? *frame slot*)
(FVALUE2? *frame slot*)

Appendix E -- The FRL Trace Function

FTRACE is FRL's tracer for frame actions. It's syntax parallels LISP's TRACE except that a predefined set of actions are traced rather than functions and a more limited set of options are available. Traceable actions are IF-ADDED, IF-REMOVED, IF-NEEDED, CREATE, DESTROY, and INSTANTIATE. Options are COND, BREAK, ENTRY and EXIT. For example,

```
(FTRACE IF-ADDED)
```

causes trace information to be printed out before and after any $IF-ADDED method is executed.

Additional information can be specified using the ENTRY and EXIT options. The COND option controls whether anything at all is printed; BREAK breaks. For example,

```
(FTRACE (IF-ADDED COND (NOT (MEMQ :SLOT '(AKO INSTANCE)))
                  BREAK (EQ :SLOT 'FOO)
                  ENTRY ( (INDIVIDUAL? :FRAME) ) ))
```

prints the usual stuff about if-added methods run on any slots other than AKO and INSTANCE, breaks if an if-added method is run for the FOO slot of a frame, and prints whether or not the frame is an Individual along with the entry information.

(FTRACE) returns a list of actions currently being traced.

(FUNTRACE) stops tracing entirely.

(FUNTRACE *action1 action2 ...*) stops tracing selectively.

Appendix F -- The FRL Frame Editor

Frames can be modified in place using FRL's Frame Editor, FRED. Changes to values in a frame have the same side-effects as FASSERT and FERASE.

(FRED *frame*)

displays *frame* on the top of the screen while recognizing a few editing commands at the bottom. (FRED) edits the previously edited frame. A cursor (.), when present, appears just before the sub-structure being edited.

W displays the whole frame. Ordinarily, the frame is compacted to fit the screen.
J moves the cursor to the beginning of the frame; its name.
F moves the cursor to the first item in the structure.
L moves the cursor to the last item.
N moves the cursor to the next item.
P moves the cursor to the previous item.
U moves up within structures.
D moves down.
G reads a name and goes to that slot.
S prints all the slots in the frame.
H prints the heritage of the current level of the frame.
K kills the next item after the cursor. It is bound to the atom ".".
I inserts a new sub-structure. Prefix your response with "%" to return the value of the expression.
. reads a name and binds the current value of "." to it.
V prints the values of the current slot.
C runs a check on the requirements in the current slot.
E reads and evaluates a single form.
Q quits.
? prints FRED's documentation.